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An Economic and Environmental Costs Computing Model of Consuming Abandoned Wind Power Heating

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Abstract – *While the wind energy resources of northern China are quite abundant, the abandoned wind rate keeps up at a high level due to the electric energy and heat coupling of the cogenerator during heating period. Consuming abandoned wind power heating facilitates degrading the abandoned wind power amount of northern China, developing consuming wind power ability and reducing the pollution. Whilst the economical efficiency of wind power heating is relatively poor due to the high construction costs, the pollutant discharge amount is low. The environmental costs are calculated, shifted into monetary costs, and then added with economic costs. The costs of consuming abandoned wind power heating include the decrement of the generation cost of wind power plant and the economic and environmental costs of thermal storage type electric heating. Taking the Environmental conservation of wind power and the decrement of the generation cost of wind power plant into consideration, not only the comparison between consuming abandoned wind power heating and cogeneration heating is more comprehensive and reasonable, but also the joint programming of wind power heating and traditional modes of heating.*

Keywords – consuming abandoned wind power heating, economic costs, environmental costs, thermal storage type electric heating.

1. INTRODUCTION

The installed capacity of wind power plants in our country keeps increasing with the continuous development of sustainable energy sources in recent years. However, the wind abandon is severe as the average abandoned wind rate of China is 17% in 2012, 11% in 2013, 8% in 2014, and 15% in 2015.

The wind energy resources of northern China are quite abundant, and wind power is mainly developed in these areas. Thus the consumption of wind power is significant to continuous improvement of wind power in these regions. Cogeneration heating is the main heating mode in northern China during the heating period. There are constraints that the cogeneration units must follow while in operation [1-3], hence there exists the electric energy and heat coupling, resulting in the lack of the system peaking capability and the abandoned wind power in winter, which is the main reason of the high abandoned wind rates in northern China. For instance, the abandoned wind rate in Jilin province in recent years is approximately 23%, where the abandoned wind amount in heating period makes up around 80% of the year-round abandoned wind amount. Adopting consuming abandoned wind power heating and cogeneration heating collectively in heating period prompts wind power consuming through supplying heat, and furthermore, it can bring down cogeneration heating amount, thus enhancing the system peaking capability and reducing the abandoned wind power amount resulting from the insufficient of the system peaking capability.

Building the economic and environmental costs computing model of consuming abandoned wind power heating is the foundation of calculating the economic and environmental costs computing model of wind power heating under the conditions of diverse heat and power demands as well as consuming abandoned wind power amount, which is significant to explore and optimize the planning of the heat source.

Scholars have been exploring the economic and environmental efficiency of wind power and cogeneration in order to enhance the utilization of wind power. A environmental costs computing model of wind power and cogeneration was established and the pollutant discharge curve of combined power generation was depicted in [4] based on extensional multi-objective economic dispatch model. The view that deploying electric boilers contributes to breaking the coupling of power and heat was put forward and an evaluation scheme of saving coals efficiency as well as a mathematical model of the national economy were built in [5].

To establish generation reasonable scheduling model, scholars have been studying characteristics of wind power. A joint optimization of rolling scheduling algorithm was proposed based on Lagrange Relaxation Algorithm aimed at the characteristics of wind power and cogeneration units in [6]. An energy-saving dispatching of wind power and cogeneration units was realized by establishing optimal models on the strength of the smart grid scheduling system in consideration of the supply side and demand side in [7]. A cogeneration and electricity heating system scheduling model was established through the control of thermal storage link in

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[8], bringing thermal storage into wind power active scheduling system. [9] proposed to establish CHP scheduling platform in provincial power grid dispatching institutions and built an abandoned wind heat storage trading strategy taking multipartite economical efficiency into consideration, realizing abandoned wind heat storage heating. [10] led in a dynamic costs coefficient in the establishment of traditional generation and wind generation scheduling model, which is calculated by the influences of the variation characteristic of wind speed and electrical load on wind power feed-in tariffs, and determined the lowest-costs scheduling plan by means of genetic algorithm, strengthening the reasonability of the regulation scheme.

There are thorough comparatively researches about the characteristics and environmental effects in existing studies. For wind power heating, there are also relatively mature theories and solutions. However, there are few associated calculation and analysis of the economic and environmental costs of consuming abandoned wind power heating, which should be brought into the comparison with traditional heating modes and CHP planning so as to decrease the abandoned wind rate, reducing emissions and promote the development of sustainable energy as well as keep the economic costs at a low level.

2. MATERIALS AND METHODS

2.1 The Economic Costs Computing Model

The wind power plant sells power that it generates to heating station through the newly built power grid. The heating station configures thermal storage type electric heating, which products heat that is sold to heating companies. Then the heating companies sell heat to users. The costs of consuming abandoned wind power heating consist of two parts. The first part is the costs of the thermal storage type electric heating, which are the incremental costs. On account of the consumption of abandoned wind power, the output of wind power plant increases during heating period and thus unit generation cost decreases. So the second part is the decrement of wind power plant's generation costs, which are the decreasing costs and actually a kind of income. For transmission costs, they are included as electricity purchasing costs of thermal storage type electric heating.

2.1.1 The Compute of the Unit Heating Costs of Thermal Storage Type Electric Heating

The specific data shows that when enhancing the output of thermal storage type electric heating, the unit heating cost reduces. And the unit heating cost can be expressed as a quadratic function as shown in Equation 1 in which the independent variable is the output.

$$uc_{thse} = a_{thse} p_{thse}^2 + b_{thse} p_{thse} + c_{thse} \tag{1}$$

where p_{thse} denotes the output of thermal storage type electric heating, a_{thse}, b_{thse}, c_{thse} respectively denote the quadratic, monomial and constant coefficients of the function, which can be calculated based on all actual costs of thermal storage type electric heating.

2.1.2 The Compute of the Decrement of Wind Power Plant's Unit Generation Costs

Similar to thermal storage type electric heating, when enhancing the output of the wind power plant, the unit generation cost reduces. And the unit generation cost can be expressed as a quadratic function as shown in Equation 2 in which the independent variable is the output.

$$uc_w = a_w p_w^2 + b_w p_w + c_w \tag{2}$$

where p_w denotes the output of the wind power plant, a_w, b_w, c_w respectively denote the quadratic, monomial and constant coefficients of the function, which can be calculated based on all actual costs of wind power plant.

When the heating amount of the thermal storage type electric heating is determined, the output of the wind power plant and the unit generation costs uc_{w2} are accordingly determined. The difference value between the unit generation costs when the consuming abandoned wind power heating project not implementing uc_{w1} and uc_{w2} is exactly the decrement of wind power plant's unit generation costs, which is expressed as Equation 3.

$$\Delta uc_w = uc_{w1} - uc_{w2} \tag{3}$$

2.2 The Environmental Costs Computing Model

The compute of the environmental costs is based on LCA theory [11]. To assess the environmental effects of consuming abandoned wind power heating, the first step is to collect and collate the resource consumption and pollutant emissions data of every link of the full life circle. Then the environmental costs are shifted into monetary costs so as to be added with economic costs.

The compute of the environmental costs includes three procedures. The first is to establish LCA models and the second is to make pollutant emissions lists. The third part is to calculate the environmental costs of every list and then compute the unit environmental cost of consuming abandoned wind power heating.

CO_2, SO_2, NOx, COD, slags and dusts are selected as the main pollutants to make pollutant emissions lists and calculate the environmental costs.

Governance cost method and pollution loss method are two widely employed methods when international scholars calculating the environmental costs. In consideration that the factors to consider in pollution loss method are relatively intricate, and in view of the

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lack of a unified standard, governance cost method is employed to compute the environmental costs.

The governance costs of SO_2, NOx, COD and dusts can be consulted from China's environmental economic accounting technical guide [12], respectively valued \$0.22 per kilogram, \$0.48 per kilogram \$2.43 per kilogram and \$0.04 per kilogram. On account that industrial wastes are not divided, in [12], the unit environmental cost of slags is consulted from Administrative Regulations on Levy and Use of Pollutant Discharge Fee, valued \$3.98 per ton. The unit environmental cost of CO_2 is valued the carbon tax at the year 2020 level proposed by China environmental protection agency in 2010, which is \$7.96 per ton.

2.2.1 The Establishment of LCA Models

There are three parts of consuming abandoned wind power heating project, namely the wind power plant system, the power transmission system and the thermal storage type electric heating system. The environmental costs of the wind power plant system and the power transmission system are embodied in electricity consumption environmental costs of thermal storage type electric heating system. Every link of all the systems in the whole life cycle is analyzed and included in the LCA models.

2.2.2 The Emission Amounts of the Systems

The environmental costs of consuming abandoned wind power heating can be divided into two parts according to the computing methods. The thermal storage type electric heating consumes power in operation, and the operation environmental costs of thermal storage type electric heating is computed based on the environmental costs of wind power generation and power transmission. Other environmental costs of thermal storage type electric heating are calculated based on the consumption amounts of building materials and construction materials, which produce environmental emissions in the production and using processes.

In order to consume wind power, the electric power that the thermal storage type electric heating consumes under operation is generated by the wind power plant. The unit generation emission amount of every pollutant is contained in CLCD, which of CO_2 is denoted by $ue_{g,C}$, SO_2 by $ue_{g,S}$, NO_x by $ue_{g,N}$, COD by $ue_{g,COD}$ and dusts by $ue_{g,d}$.

The emission amounts of electricity transmission can be calculated by the consumption amounts of building materials and construction materials of the power grid, which are not contained in CLCD. The transmission emission amount of CO2 is denoted by $ue_{t,C}$, SO2 by $ue_{t,S}$, NOx by $ue_{t,N}$, COD by $ue_{t,COD}$, slags by $ue_{t,sl}$ and dusts by $ue_{t,d}$.

The main resource consumption and environmental emissions of electricity transmission occur at the process of construction, and the emissions of other processes are relatively so small that can be ignored. The delivery conduits of consuming abandoned wind power heating project included wind power delivery conduit and the delivery conduit from power grid to the heating station. The latter is far shorter than the former and the emissions of it can be ignored. The main building materials of wind power delivery conduit contain towers, wires, insulators, and metal fittings, whose major components are steels, aluminum, iron, ceramics and glasses. According to the consumption amounts of the building materials and power transmission, the unit emission amount of every pollutant can be enumerated.

According to the unit generation emission amounts, the unit transmission emission amounts, the electric boiler thermal efficiency η_{thse} and the transmission loss rate η_l, the unit operation emission amounts of thermal storage type electric heating can be enumerated as Equation 4.

$$ue_{thse,op,x} = \frac{ue_{g,x} + ue_{t,x}}{\eta_{thse}(1-\eta_l)} \quad (4)$$

where $x \in F_e = \{C, S, N, COD, sl, d\}$, and $ue_{g,sl} = 0$. Other periods of thermal storage type electric heating cover the production and transportation of electric heating boiler plant building materials, the construction of the boiler plant, the production and transportation of electric heating boilers manufacturing materials, the manufacture of the electric heating boilers, the production and transportation of electric heating auxiliary equipment manufacturing materials and the manufacture of electric heating auxiliary equipment. The emission amount during those periods of CO_2 is denoted by $ue_{thse,ot,C}$, SO_2 by $ue_{thse,ot,S}$, NO_x by $ue_{thse,ot,N}$, COD by $ue_{thse,ot,COD}$, slags by $ue_{thse,ot,sl}$ and dusts by $ue_{thse,ot,d}$.

2.2.3 The Unit Environmental Costs Compute of Consuming Abandoned Wind Power Heating

On the basis of the unit environmental cost of every pollutant and the calculation of the emission amounts of every pollutant in all consuming abandoned wind power heating processes, the units heating environmental costs of the pollutants are determined as Equation 5.

$$uc_e = \sum_{x \in F_e} (ue_{thse,op,x} + ue_{thse,ot,x}) \times c_{e,x} \quad (5)$$

where $c_{e,x}$ devotes the unit environmental cost of every pollutant.

2.3 The Economic and Environmental Costs Computing Model

From the above, the economic and environmental costs consist of two sections, the economic and environmental costs of the thermal storage type electric heating

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expressed as Equation 6 and the decrement of the wind power plant generation costs expressed as Equation 7.

$$uc = uc_{thse} + uc_e \quad (6)$$

$$\Delta uc_w = uc_{w1} - uc_{w2} \quad (7)$$

2. RESULTS

A case is analyzed below to compare the economic and environmental costs of consuming abandoned wind power heating and cogeneration heating. In that case, the installed capacity of the wind power plant is 400MW, and the output of the thermal storage type electric heating is 4×10MW. For comparison, the output of the thermal power plant is 2×300MW.

When the output of the thermal storage type electric heating reaches 80% level, the unit economic costs is $27.78/GJ and the unit generation costs of wind power is $25.52/GJ. The unit generation costs when the consuming abandoned wind power heating project not implementing is $42.81/GJ.

According to data base CLCD, the unit generation emission amount of every pollutant is enumerated as Table 1.

Table 1. The unit generation emission amounts of the wind power plant.

Pollutant	Amount(kg)
CO_2	6.0900
SO_2	0.0168
NO_x	0.0123
COD	0.0258
dusts	0.0033

According to the consumption amounts of the building materials and power transmission, the unit emission amount of every pollutant is enumerated as Table 2.

Table 2. The unit emission amounts of power transmission.

Pollutant	Amount(kg)
CO_2	1.5958
SO_2	0.0061
NO_x	0.0049
COD	0.0071
slags	0.4021
dusts	0.0103

The heating period in northern China valued 120 days, the electric boiler thermal efficiency valued 98%, the transmission loss rate valued 10%, the unit operation emission amount of thermal storage type electric heating is determined based on the emission amounts of wind power generation and power transmission as Table 3.

Table 3. The unit operation emission amount of thermal storage type electric heating.

Pollutant	Amount(kg)
CO_2	7.9874
SO_2	0.0239
NO_x	0.0180
COD	0.0342
slags	0.4468
dusts	0.0148

The transportation distance valued 25 kilometer by medium-sized gasoline truck, the materials weight in transportation valued 1.2 times of the main building and construction materials weight in all those periods, the unit emission amounts of other periods of thermal storage type electric heating is determined based on data in CLCD as Table 4.

Table 4. The unit emission amount of thermal storage type electric heating in other periods.

Pollutant	Amount(kg)
CO_2	0.2727
SO_2	0.0022
NO_x	0.0010
COD	0.0008
slags	0.1675
dusts	0.0014

The units heating environmental costs of the pollutants are determined as Table 5.

Table 5. The unit environmental cost of every pollutant.

Pollutant	Operation periods cost of every ten thousand GJ ($)	Other periods cost of every ten thousand GJ ($)
CO_2	635.45	21.64
SO_2	51.39	4.77
NO_x	86.71	4.77
COD	832.57	19.41
slags	17.82	6.68
dusts	5.41	0.48

All the environmental costs added up, the total unit environmental costs of consuming abandoned wind power heating is determined as $0.1687/GJ.

4. DISCUSSIONS

When the output of the thermal storage type electric heating reaches 80% level, the total unit economic and environmental costs is $27.90/GJ. When the output of the thermal power plant reaches 65% level, the unit economic costs is $19.19/GJ. The environmental costs is calculated similarly to the thermal storage type electric heating and determined as $7.34/GJ. Thus the total unit economic and environmental costs is $26.53/GJ.

The decreasing generation costs of the wind power plant not considered, the unit economic cost of the thermal storage type electric heating is 1.44 times of the cogeneration heating, whilst the unit environmental cost of cogeneration heating is 43.53 times of the thermal storage type electric heating. The unit economic and environmental cost of the thermal storage type electric heating is 1.05 times of the other, which is $1.36/GJ higher. When more types of environmental pollutants considered and the emission costs of the pollutants valued higher, the total costs of the thermal storage type electric heating is able to get more close to or even less than the cogeneration heating.

Furthermore, the decreasing generation costs of the wind power plant should be taken into account. The unit generation costs when the consuming abandoned wind power heating project not implementing is $42.81/GJ. Wind power employed to supply heat during the heating period, when the output of the thermal storage type electric heating reaches 80% level, the unit generation costs of wind power is $25.52/GJ, which is $17.29/GJ less and the droop rate is 40.39%.

On account that the installed capacity of the wind power plant is relatively small, the environmental benefit of consuming abandoned wind power heating is evident but restricted. When consuming abandoned wind power heating becomes generally applied in northern China, the environmental benefit is able to get remarkable. Moreover, after carbon tax is levied and its level gradually rises, the environmental benefit will more considerable.

The wind power plant installed capacity is relatively small and the equipment investment is high. In consequence, the descend range of unit generation costs is large when the output increases. Consuming abandoned wind power heating has extremely obvious effect on the decrease of wind power generation and reduce the abandoned wind rate, which is able to improve the current situation where a great deal of the installed capacity is wasted and the abandoned wind rate is particularly high during the heating period.

5. CONCLUSION

An economic and environmental costs computing model of consuming abandoned wind power heating is developed in this paper, in which the economic costs and the environmental costs are calculated respectively. The latter is shifted into monetary costs and added with economic costs, both the economic and environmental impacts taken into consideration. Moreover, not only the incremental costs are considered but also the decreasing cost owing to the increase of the wind power plant's output, reflecting the costs changes of the main subjects comparatively comprehensively. The establishment of the model is conducive to not only compare the economic and environmental efficiency of consuming abandoned wind power heating and cogeneration heating but also optimize CHP planning.

The economic and environmental costs of a case is calculated based on this model. The results shows that the economic and environmental costs of the thermal storage type electric heating is a little more than that of the thermal power plant considering the emission of CO2, SO2, NOx, COD, slags and dusts. When more pollutants are taken into consideration, besides, after carbon tax is levied and its level gradually rises, the costs of the thermal storage type electric heating is supposed to exceed the costs of the thermal power plant. Moreover, the decrement of the wind power plant generation costs due to consuming wind power heating is extremely significant, which promotes the wind power plants to invest the thermal storage type electric heating and supply heat during the heating period.

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REFERENCES

[1] Zeng Y. and Y Sun. 2014. An improved particle swarm optimization for the combined heat and power dynamic economic dispatch problem. *Electric Power Components and Systems* 42 (15): 1700-1716.

[2] Zepeng G., Chongqing K., Xinyu C., Jianhua B., and Lu C., 2015. Considering the heat supply network constraints operation optimization of electric and heating energy integrated system and consuming wind power benefit analysis. *Proceedings of the CSEE* 35 (14): 3596-3604.

[3] Zhisheng Z., 2015. Cogeneration technology economy analysis. Jilin University.

[4] Piperagkas G.S., Anastasiadis A.G., Hatziargyriou N.D., 2011. Stochastic PSO-based heat and power dispatch under environmental constraints incorporating CHP and wind power units. *Electric Power Systems Research* 81 (1): 209-218.

[5] Quan L., Hao J., Tianyou C., Haixia W., Yang L., Weidong L., 2014. Thermal power plant consuming wind power scheme based on the electric boiler and national economic evaluation. *Power System Automation* 38 (1): 6-12.

[6] Jianhua C., Wenchuan W., Boming Z., Yong S., 2012. Consuming large-scale wind power cogeneration unit rolling scheduling strategy. *Power System Automation* 36 (24): 21-27.

[7] Hongyu L., Jianwei M., Kai W., Yulong Y., Jingbo Z., Ling S., and Bin Q., 2011. Grid energy-efficient scheduling containing cogeneration and wind turbines. *Electric Power Automation Equipment* 31 (11): 18-22.

[8] Lei C., Fei X., Xiao W., Yong M., Maosheng D. and Peng H., 2015. Implementation mode and effect analysis of heat storage promoting wind power consuming capacity. *Proceedings of the CSEE* 35 (17): 4283-4290.

[9] Yanfeng G., Xiaofe L., Yangyang G., Ming S., Mingyi S. and Liyong S., 2015. Abandoned wind thermal storage heating technology solutions based on CHP dispatch. *Smart Grid* 3(10): 901-905.

[10] Geeth K., Sharmila V. and Keerthivasan D.K., 2015. Design of economic dispatch model for Gencos with thermal and wind powered generators. *Electrical Power and Energy Systems* 68: 222–232.

[11] Hischier R., Weidema B.P., Jungbluth N. and Nemecek T., 2010. *Implementation of life cycle impact assessment methods*. Swiss Centre for Life Cycle Inventories, Dubendorf.

[12] Fang Y., Dong C., Hongqiang J., Yue Z., Shuting G., Gang Y., Jingbo Z. and Wen P., 2009. China's environmental economic accounting technical guide. *China Environmental Science Press*, Beijing.

[13] State Development Planning Commission, Ministry of Finance, State Environmental Protection Administration, State Economic and Trade Commission. *Administrative Regulations on Levy and Use of Pollutant Discharge Fee.* 2003-02-28.